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Technical and Economical Analysis of Manure Management in Loose Housing Systems for Dairy Cows

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Abstract. Manure management affects work organization, costs, hygiene and animal welfare on dairy farms; for this reason new cowsheds should be planned according to specific conditions and requirements of farms by comparing technical and economical performances for different manure management systems. The main aim of the research was to improve housing systems and manure management in dairy farms in order to favor better conditions of welfare and hygiene of cows, to reduce costs of dairy farms and to produce solid manure. Most dairy farms in Emilia-Romagna need to produce solid and liquid manure instead of semi-solid manure for agronomic and environmental reasons. Hygienic conditions of milking cows were monitored in eleven reference dairy farms. Costs of building, equipment, labor, electric usage, machines and litter were calculated and compared for nine standard cowsheds with different lying areas and manure management. Cows' skin dirtiness is higher in cowsheds with deep bedded and sloped bedded lying areas than in cubicle cowsheds even if the consumption of bedding is higher. In cubicle cowsheds acceptable hygienic conditions for cows cannot be achieved by avoiding the use of bedding or synthetic mattresses. Cubicles with litter and cleaning with automatic scrapers or tractor mounted scraper show low costs for manure management and low cow dirtiness scores. Cubicles with small use of litter, gravity flushing system and mechanical separator can be advisable for large herds.

Keywords. Dairy farms, housing, bedding, dairy wastes, management, cost analysis.

Introduction

Housing system affects work management and cows' welfare on dairy farms. In comparison with tied housing, loose housing systems can lower labor needs per head and get better safety and hygienic conditions for workers. Moreover, it can improve welfare, health, hygiene and milk quality in dairy cows. Better hygienic conditions for cows improve the health of udders and reduce frequencies and seriousness of mastitis. The main aim of the project was to improve loose housing systems and waste management in dairy farms to improve welfare and hygiene of cows and to limit costs and environmental impact of dairy farms. An approach to the project was to compare hygienic conditions of cows and costs for manure management of different loose housing systems used in dairy farms of Emilia-Romagna Region of Italy.

Materials and Methods

Dirtiness of milking cows' skin was tested in eleven reference dairy farms to compare hygienic conditions of cows in loose housing systems with different lying areas and manure management. These farms were selected among a sample of forty dairy farms already investigated within a survey on manure management to be representative for the most popular and most modern loose housing systems for dairy cattle in Emilia-Romagna.

A score method was used for analyzing five anatomical parts of their body: sacro-ischiatic part viewed from the back; back side of the udder viewed from the back; front side of the udder viewed from both sides; legs; feet. The score for each anatomical part varies from 0 to 2 within the following steps: 0 = clean; 0.5 = a few small dirty areas; 1 = less than 50% covered with dirt; 1.5 = more than 50% covered with dirt; 2 = totally covered with dirt. Therefore the total score for each cow ranges from 0 to 10. The number of total scores to be collected in each farm are more than 50% of the number of milking cows in the herd; choice of cows to be scored is random. The mean value of the dirtiness total scores of cows tested in each cowshed expresses the cows' dirtiness score of that cowshed (Houdoy, 1992).

In each cowshed type of lying area, type of bedding, bedding consumption, manure removal system and type of flooring were analyzed (Table 1). The following kind of lying areas were compared:

- cubicles with bedding;
- cubicles with mattress and bedding;
- cubicles with mattress and without bedding;
- cubicles without bedding and mattress;
- sloped bedded floor;
- deep bedded floor.

Cubicles on farms A3 and A4 are provided with mattresses to improve cow comfort and to avoid or minimize the use of bedding. Farms A1, A2, A3 and A4 are equipped with manure pumps for flushing; while Farms A7, A8, A9, A10 and A11 are provided with automatic scraper conveyers.

Table 1 – Technical parameters of manure handling systems and dirtiness score of milking cows in eleven reference cowsheds.

Farm	Lying area	Type of bedding	Bedding use kg cow ⁻¹ d ⁻¹	Type of flooring	Manure removal system	Dirtiness Score Mean±SD
A1	Cubicles	Sawdust	2.0	Solid	Pump flushing	2.58±1.09
A2	Cubicles	Chopped straw	1.0	Solid	Gravity flushing	3.45±1.17
A3	Cubicles - mattresses	Sawdust	0.7	Slatted	Pump flushing	2.65±1.06
A4	Cubicles - mattresses		0.0	Slatted	Pump flushing	3.75±1.53
A5	Cubicles	Sawdust	0.4	Slatted	Storage pit	3.95±1.15
A6	Cubicles		0.0	Slatted	Storage pit	4.68±1.55
A7	Cubicles	Straw	3.3	Solid	Scrapers	2.38±1.21
A8	Cubicles	Straw	0.5	Solid	Scrapers	3.70±1.74
A9	Sloped floor	Straw	3.0	Solid	Scrapers	5.01±1.67
A10	Sloped floor	Chopped straw	2.4	Solid	Scraper	5.44±1.27
A11	Deep bedded floor	Straw	4.8	Solid	Tractor loader - scraper	4.47±1.49

Overall annual costs for manure management were estimated for nine theoretical standard cowsheds, planned and sized for 100 dairy cows, representative for the most popular and the most modern manure management systems for loose housed dairy cows. For each standard cowshed the following major features were defined:

- B1 – Cowshed with two “back to back” rows of 2.5 kg cow⁻¹d⁻¹ straw bedded cubicles, 100 kW tractor equipped with front fork loader and 70 kW tractor equipped with straw distributor machine for bedding, solid floor alleys, 60 kW tractor equipped with scraper for once a day manure removal, below-ground liquid manure transfer pit equipped with lift pump (2 kW), partially below-ground tank for liquid manure storage and concrete platform for solid manure storage (figure 1).
- B2 – Cowshed with two “back to back” rows of 2.5 kg cow⁻¹d⁻¹ straw bedded cubicles, 100 kW tractor equipped with front fork loader and 70 kW tractor equipped with straw distributor machine for bedding, solid floor alleys, two automatic scrapers (5.2 kW) and cross-conveyor elevator (1.5 kW) for twice a day manure removal, below-ground liquid manure transfer pit equipped with lift pump (2 kW), partially below-ground tank for liquid manure storage and concrete platform for solid manure storage.
- B3 – Cowshed with two “back to back” rows of 1 kg cow⁻¹d⁻¹ straw bedded cubicles, 100 kW tractor equipped with front fork loader and 80 kW tractor equipped with straw chopper distributor machine for bedding, solid floor alleys, two automatic scrapers (5.2 kW) and cross-gutter equipped with jet-pump (2 kW) for twice a day manure removal, below-ground manure transfer pit equipped with lift pump (2 kW), mechanical rotating screen separator (1 kW), partially below-ground tank for liquid manure storage and concrete platform for separated solids storage.
- B4 – Cowshed with two “back to back” rows of 1 kg cow⁻¹d⁻¹ straw bedded cubicles, 100 kW tractor equipped with front fork loader and 80 kW tractor equipped with straw chopper distributor machine for bedding, solid 1.5% sloped floor alleys, gravity flushing system for twice a day manure removal, 22 m³ vertical cylinder tank for flush storage, cross-gutter, below-ground manure transfer pit

equipped with lift pump (2 kW), mechanical rotating screen separator (1 kW), partially below-ground tank for liquid manure storage equipped with lift pump (2 kW) and concrete platform for separated solids storage (figure 1).

- B5 – Cowshed with two “back to back” rows of 1 kg cow⁻¹d⁻¹ straw bedded cubicles, 100 kW tractor equipped with front fork loader and 80 kW tractor equipped with straw chopper distributor machine for bedding, solid 1.5% sloped floor alleys, pump flushing for three times a day manure removal, 30 kW electric high flow flushing pump, cross-gutter, below-ground manure transfer pit equipped with lifting pump (2 kW), mechanical rotating screen separator (1 kW), partially below-ground tank for liquid manure storage and concrete platform for separated solids storage.
- B6 – Cowshed with two “back to back” rows of cubicles with plastic mattresses and small use of sawdust (1 kg cow⁻¹d⁻¹ 4 months per year), 100 kW tractor equipped with front fork loader and 20 kW light tractor equipped with small trailer for bedding, slatted floor alleys, below-ground storage pits under slatted floor.
- B7 – Cowshed with two “back to back” rows of cubicles equipped with plastic mattresses and small use of sawdust (1 kg cow⁻¹d⁻¹ 4 months per year), 100 kW tractor equipped with front fork loader and 20 kW light tractor equipped with small trailer for bedding, slatted floor alleys, below-ground channels under slatted floors, pump flushing for once a day manure removal, electric flushing pump (7.5 kW), cross-gutter, below-ground manure transfer pit equipped with lift pump (2 kW), mechanical rotating screen separator (1 kW), partially below-ground tank for liquid manure storage and concrete platform for separated solids storage.
- B8 – Cowshed with sloped bedded floor in lying area (3 kg cow⁻¹d⁻¹), 100 kW tractor equipped with front fork loader and 80 kW tractor equipped with straw chopper distributor machine for bedding, automatic scraper (3 kW) in feeding area and cross-conveyor elevator (2 kW) for twice a day manure removal, liquid manure transfer pit equipped with lift pump (2 kW), partially below-ground tank for liquid manure storage and concrete platform for solid manure storage (figure 1).
- B9 – Cowshed with deep bedded lying area (5 kg cow⁻¹d⁻¹), solid floor feeding alley, 100 kW tractor equipped with front fork loader and 70 kW tractor equipped with straw distributor machine for bedding, automatic scraper (3 kW) in feeding area for twice a day manure removal and 100 kW tractor equipped with front shovel loader for solid manure removal in lying area, below-ground liquid manure transfer pit equipped with lift pump (2 kW), partially below-ground tank for liquid manure storage and inside deep bedded lying area for solid manure storage (figure 1).

Storage tanks and platforms are made of reinforced concrete and are sized to store manure and milking center wastes for four months. All cowsheds produce solid and liquid manure except B6. Building costs for each cowshed were estimated using official average prices (update 2005) for agricultural improvement works, approved by the Regional Government of Emilia-Romagna. Annual fixed costs were calculated as the sum of depreciation rates (3% for buildings and fixed installations, 12% for equipment for removal and treatment of manure), maintenance rates (0.3% for buildings, 1% for fixed installations, 4% for equipment for removal and treatment of manure) and insurance rates (0.3%) of investments for buildings, installations and equipment directly or indirectly related to manure management. Comparable investments for manure management of each standard cowshed were calculated as the sum of building costs of outside storage structures and equipment for manure and liquid wastes and further building costs of inside barns (e.g. slatted floor, channels, equipment) in comparison with the cheapest cowshed B1; investments for manure management of B1 concern only outside storage structures. Annual variable costs for manure management were calculated taking into account the most common and proper equipment, materials and work organization used in Emilia-Romagna Region for each manure management system in nine standard cowsheds to lower labor needs and total costs.

Following machines and respective operating costs per hour (except for driver cost) were considered for bedding and manure removal operations:

- 100 kW tractor equipped with front fork loader for unloading straw bales or sawdust storage, 25.47 €/h;
- 70 kW tractor equipped with straw distributor machine for spreading straw in lying area, 18.47 €/h;
- 100 kW tractor equipped with front shovel loader for removing solid manure from deep bedded lying area, 25.47 €/h;
- 80 kW tractor equipped with straw chopper distributor machine for spreading straw in lying area, 23.88 €/h;
- 60 kW tractor equipped with scraper for once a day manure removal from alleys in B1, 16.49 €/h;
- 20 kW light tractor equipped with small trailer for distribution of small amount of sawdust in cubicles from slatted floored alleys in B6 and B7, 8.41 €/h.

Whole cost of tractors and machines are not assigned only to manure and bedding handling as the equipment is had also for other uses such as for tilling and harvesting forage crops and for feeding cows.

Labor needs and working times of machines and equipment for bedding and manure handling were defined with reference to average data collected within a survey on manure management carried out in forty loose housing dairy cowsheds (Tables 2 and 3). Three types of bedding materials are used:

- straw on farms B1, B2 and B9;
- chopped straw on farms B3, B4, B5 and B8;
- sawdust on farms B6 and B7.

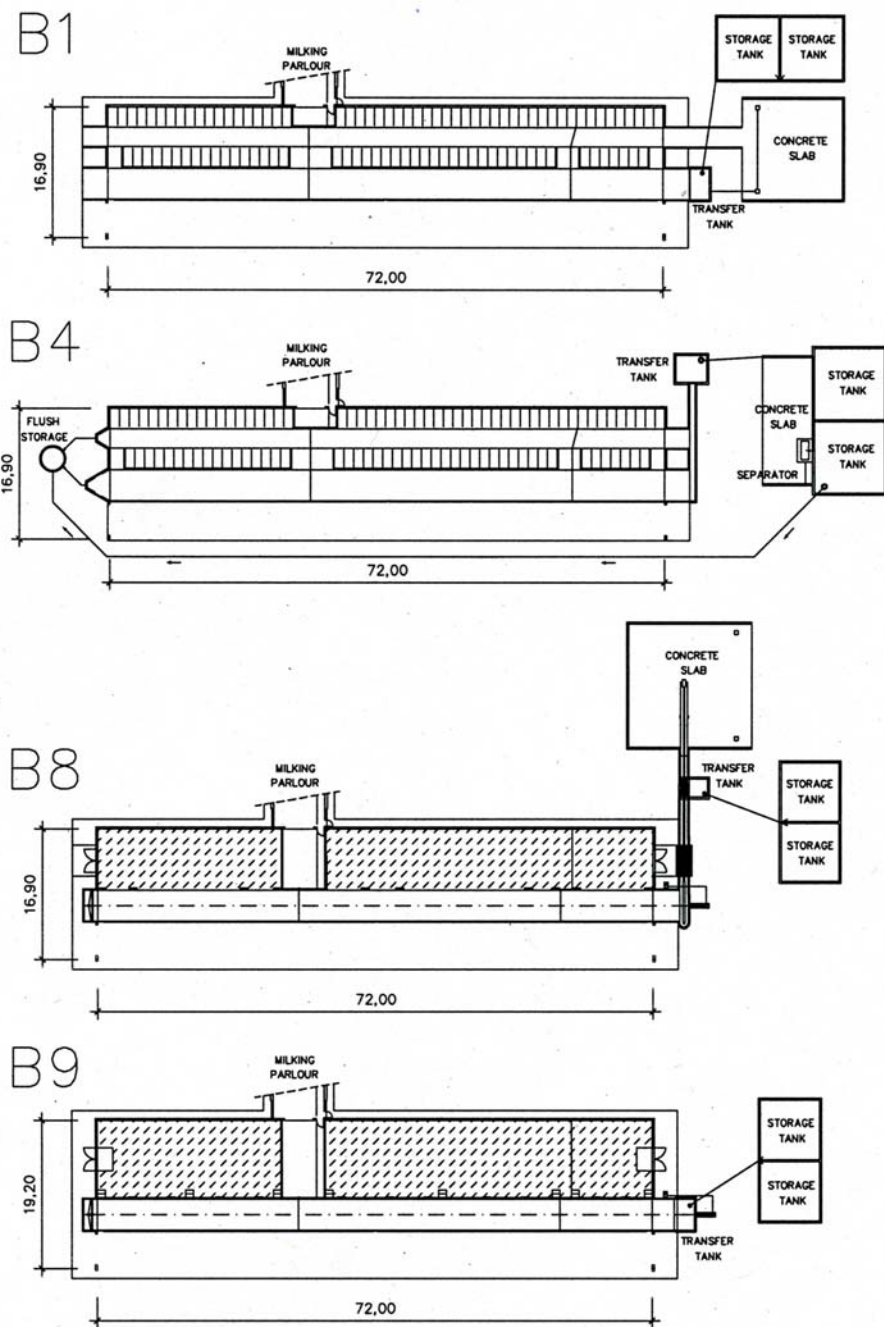


Figure 1. Plans of standard cowsheds B1, B4, B8 and B9.

The use of bedding requires extra labor for distribution and for removing manure from bedded resting areas; this is the main disadvantage of using bedding. Obviously this kind of labor can be avoided in cubicle cowsheds without using bedding.

Table 2 – Labor needs and working times of machines for bedding and manure handling in nine standard cowsheds.

Type of labor	Working times (s cow ⁻¹ d ⁻¹)								
	B1	B2	B3	B4	B5	B6	B7	B8	B9
100 kW tractor with front fork loader	2	2	1	1	1	0.3	0.3	2.5	4
70 kW tractor with straw distributor	9	9							12
80 kW tractor with straw chopper distributor			9	9	9			9	
20 kW light tractor with small trailer						4	4		
60 kW tractor with scraper	15								
100 kW tractor with front shovel loader									4
Driver labor	26	11	10	10	10	4.3	4.3	11.5	20
Manual labor						4.7	4.7		
Total manual and driver labor	26	11	10	10	10	9	9	11.5	20

Table 3 – Electric power and working times of equipment manure removal in nine standard cowsheds.

Type of equipment	Working time (s cow ⁻¹ d ⁻¹)								
	B1	B2	B3	B4	B5	B6	B7	B8	B9
Lifting pump (2 kW)	3.7	3.7	5.9	93	131		139	3.3	3.5
Automatic scraper – feeding area (3 kW)		48	48					48	48
Automatic scraper – lying area (2.2 kW)		48	48						
Cross conveyor elevator (1.5 kW)		36						36	
Rotating filter separator (1 kW)			5.9	49	131		139		
Jet pump (2 kW)			36						
High flow rate flushing pump (30 kW)					3.6				
Flushing pump (7.5)							28		

The official wage for agricultural workers of 11.3 €/h, assessed by local trade union of Reggio Emilia for 2005, was assumed for the cost of labor. The cost of straw of 55.76 €/t was calculated as the mean of official monthly prices of straw in Emilia-Romagna from August 2002 to July 2005. The cost of sawdust of 160 €/t is the market price in 2005 of an Italian commercial product for dairy farms. The cost of electricity was calculated with reference to the official national rates taking into consideration the total electric power and the annual electric usage estimated for each standard cowshed; on average the cost of electricity was 0.17 €/kWh, ranging from 0.15 €/kWh for cowshed B3 to 0.20 €/kWh for cowshed B5.

Results and Discussion

Eleven reference real dairy cowsheds were studied to compare hygienic conditions of milking cows housed with different housing systems and different manure handling systems and management of the lying area (Table 1). Dirtiness scores were collected from 804 Holstein milking cows; the number of cows tested per farm varies from 60 to 99. The study highlights significant differences (one-way ANOVA) among means of dirtiness scores of cows housed with different housing systems (Table 4) and with different amount of bedding (Table 5).

Table 4 – Dirtiness score for milking cows in loose housing systems with different lying areas.

Number of Farms (n)	Lying Area Type	Dirtiness score (Mean)
8	Cubicles	3.31 ^A
2	Sloped bedded floor	5.21 ^C
1	Deep bedded floor	4.47 ^B
General sample mean		3.84

^{A, B, C}) P < 0.01

Cows housed with cubicles are cleaner (3.31) than cows housed with deep bedded floor (4.47) or sloped floor (5.21). Moreover, relevant differences of dirtiness scores were found in cowsheds provided with cubicles without mattresses (table 3). Best hygienic conditions of cows were found on farm A7 in which the lowest dirtiness score of cows (mean value 2.38) is related to the use of a large quantity of bedding (3.3 kg

cow⁻¹d⁻¹). Good hygienic conditions of milking cows have been found also on farm A1 (mean value of dirtiness score of 2.58) in which cubicles were provided with 2 kg cow⁻¹d⁻¹ of sawdust.

Table 5 – Dirtiness score for milking cows housed in cubicles without mattresses with different amount of bedding.

Farm	Manure handling system	Bedding (kg cow ⁻¹ d ⁻¹)	Dirtiness score (means)
A7	Scraper – solid floor	3.3	2.38 ^A
A1	Flushing – solid floor	2.0	2.58 ^A
A2	Flushing – solid floor	1.0	3.45 ^B
A8	Scraper – solid floor	0.5	3.70 ^{BC}
A5	Flushing – slatted floor	0.4	3.95 ^C
A6	Flushing – slatted floor	0.0	4.68 ^D

A, B, C, D) P < 0.01

The study points out the worse hygienic conditions of cowsheds of farm A6 where cubicles are not bedded and are not provided with mattress; for this farm the mean dirtiness score (4.68) is almost twice the score of farm A7 (2.38) and is between the mean values of deep bedded floor cowshed (4.47) and sloped bedded floor cowsheds (5.21). Intermediate values of dirtiness scores have been calculated for farm A2, A5 and A8. For cowsheds of farms A3 and A4 with cubicles provided with mattress one-way ANOVA points out a significant difference (P<0,01) between dirtiness scores of cows housed using 0.7 kg cow⁻¹d⁻¹ of sawdust (2.65) and cows without using bedding (3.75); the first value is quite similar to the mean score of farm A1 (2.58) in which an amount of 2 kg cow⁻¹d⁻¹ is used instead of using 0.7 kg cow⁻¹d⁻¹. A quite significant difference (P=0.05) was found between dirtiness score of cows on farms A9 (5.01) and A10 (5.44) with sloped floor in lying areas and different usage of straw; the mean scores are very high for both farms but the highest score was found in the farm A10 using less bedding than farm A9 (2.4 kg cow⁻¹d⁻¹ vs 3 kg cow⁻¹d⁻¹).

Table 6 – Technical parameters of manure handling systems and electric usage of nine standard cowsheds.

Farm	Lying area	Type of bedding	Bedding use kg cow ⁻¹ d ⁻¹	Type of flooring	Manure removal system	Electric usage Wh/cow ⁻¹ d ⁻¹
B1	Cubicles	Straw	2.5	Solid	Tractor scraper	2
B2	Cubicles	Straw	2.5	Solid	Scrapers	86
B3	Cubicles	Chopped straw	1.0	Solid	Scrapers	94
B4	Cubicles	Chopped straw	1.0	Solid	Gravity flushing	66
B5	Cubicles	Chopped straw	1.0	Solid	Pump flushing	140
B6	Cubicles	Sawdust	0.3	Slatted	Storage pits	0
B7	Cubicles	Sawdust	0.3	Slatted	Pump flushing	347
B8	Sloped bedded floor	Chopped straw	3.0	Solid	Scraper	57
B9	Deep bedded floor	Straw	5.0	Solid	Scraper - tractor loader	42

Table 6 shows electric usage estimates for manure removal systems in nine standard cowsheds. Electric consumption of cowsheds provided with scraper conveyors varies from 42 Wh/cow⁻¹d⁻¹ for deep bedded cowshed without mechanical separator (B9) to 94 Wh/cow⁻¹d⁻¹ for cubicle farm B3 with mechanical separator. In the gravity flushing system (B4), recycled liquid manure is loaded in an above ground vertical cylinder shaped tank by a 2 kW electric pump operating 74 minutes per day to achieve the most suitable hydraulic pressure and flow rate (500 l/s) through the flush valve. Pump flushing system on farm B5 works 6 minutes per day by means of a 30 kW high flow rate (330 l/s) electric pump while on farm B7 a 7.5 kW electric pump works 45 minutes per day. A mechanical rotating filter separator operates by means of a 1 kW electric motor and a 2 kW electric pump 82 minutes per day on farm B4, 218 minutes per day on farm B5 and 230 minutes per day on farm B7. The highest daily electric usage for manure removal was calculated for farms B7 and B5 provided with mechanical separator and flush pump operating for a long time during the day. Electric usage for flushing sloped solid floor is higher on farm B5 than on farm B4 (140 vs 66 Wh/cow⁻¹d⁻¹) because of the high electric input of the flush pump. The cubicle cowshed with storage pits under slatted floor does not consume electric energy but this advantage can be offset by relatively high concentration of fermentation gas (ammonia, hydrogen sulphide) and flies proliferation inside the barn.

Costs for manure removal and lying area management are shown in Table 7. Variable costs for bedding and manure removal vary from 33.85 to 189.67 €cow⁻¹year⁻¹ (87.87 €cow⁻¹year⁻¹ on average) depending on use of labor, bedding, and equipment.

Table 7 – Costs for lying area management and manure removal of nine standard cowsheds.

Farm	Fixed costs (€cow ⁻¹ year ⁻¹)	Variable costs (€cow ⁻¹ year ⁻¹)					Overall costs (€cow ⁻¹ year ⁻¹)
		Bedding	Machines	Electricity	Labor	Total	
B1	45.83	50.88	47.10	0.13	29.79	127.25	173.73
B2	83.53	50.88	22.02	5.02	12.61	90.53	174.05
B3	126.79	20.35	24.37	5.55	11.46	61.74	188.50
B4	140.14	20.35	24.37	3.90	11.46	60.08	200.22
B5	154.10	20.35	24.37	10.14	11.46	66.33	220.43
B6	90.49	19.27	4.26	0.00	10.31	33.85	124.65
B7	177.84	19.27	4.26	19.17	10.31	53.02	231.16
B8	53.64	63.70	28.25	3.53	13.18	108.66	162.30
B9	49.41	101.76	44.09	2.57	41.25	189.67	239.08

Highest overall costs were calculated for cowsheds B9 using large amount of straw, labor and equipment for straw distribution and solid manure removal and for cowshed B7, using small amounts of bedding, labor and equipment but requiring high investments for inside and outside structures and equipment (flushing pump, separator). In cowshed B7 channels under slatted floor are not considered efficient for dairy manure removal in Italian climates without using flushing systems or scrapers. Lowest overall cost of cowshed B6 is related to the lowest variable costs for bedding, equipment, electricity and labor; nevertheless this solution is not advisable in Italy for new cowsheds because manure storage under slatted floors is going to be dropped from the directive 91/676/CE. Reduced use of bedding in cowshed B3, B4, B5, B7 does not imply overall cost saving as a mechanical separator is required to produce solid manure.

Conclusions

The research shows the importance of housing systems to keep milking cows in acceptable hygienic conditions and to lower management costs for bedding and manure removal. Most dairy farms of Emilia-Romagna need to produce solid and liquid manure instead of semi-solid manure for agronomic and environmental reasons: more efficient application of solid and liquid manure to forage crops such as permanent meadows and alfalfa; better compliance with environmental regional regulations.

Use of bedding increases labor need for distribution of straw or sawdust and, especially, for manure removal in deep bedded lying areas. Cowsheds with deep bedded floor and sloped bedded floor in lying area are not advisable because of the high level of cow skin dirtiness even though management cost of cowsheds with sloped bedded floor is relatively low. Best hygienic conditions have been assessed in cubicle cowsheds using plenty of straw (3.3 kg cow⁻¹d⁻¹) or sawdust (2 kg cow⁻¹d⁻¹). However acceptable hygienic conditions cannot be achieved without using a proper amount of bedding or synthetic mattresses in cubicles. As synthetic mattresses without bedding can assure acceptable cow hygienic conditions, they can be adopted to lower bedding costs and labor needs; however cow skin dirtiness can be reduced very much by spreading a small amount of chopped straw or sawdust on mattresses. Gravity flushing systems require less investments, electric power and electric usage than pump flushing. Combined with cubicles and mattresses or proper amount of bedding it can be suitable for modern cowsheds to minimize labor need and electric usage; moreover, in cowsheds for large herds the use of the same flushing storage for cleaning several alleys reduces building investments, fixed costs and overall annual costs for manure management.

Although the economic analysis of bedding and manure management does not show big difference in overall costs for different housing and manure management systems, on-farm availability and costs of labor, bedding materials, equipment and electric energy should be considered when addressing a dairy farmers' choice of the most suitable and low cost housing and manure management systems.

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